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Arctic Unit

Montreal, Que.

Circular No. 4

Studies on the Sustainable Catch of Harp Seals in the Western North Atlantic

by

D. E. Sergeant

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E R R A T A

ge 1, paragraph 1, line 8, for "70,000" read "60,000"; line 9, for "55,000" read "46,000"; line 10, for "240,000" read "232,000".

ge 3, paragraph 3, line 10 should read "Fiskeriundersøgelser".

ge 12, paragraph 1, last line for "Fig. 3" read "Fig. 6".

ge 27, paragraph 2, line 5. Delete the words "of life".

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SUMMARY

The mean annual catch of harp seals by ships in the western North Atlantic in the decade 1949 to 1958, that is, after the postwar recovery of the sealing fleet, was 186,369 young and 76,063 immatures and adults. This compares with 131,105 young and 26,147 immatures and adults for the prewar decade 1930 to 1939. To both must be added a landsmen's catch, for which imcomplete statistics are available, of about 60,000 seals per annum. The majority of these, perhaps 46,000, consist of young. The total annual catch of young at the present time then averages about 232,000.

Aerial surveys in 1950 and 1951 estimated an annual production of about 645,000 young, 215,000 of these born in the Gulf of St. Lawrence and about 430,000 on the Front. A survey in 1959 was not complete enough for firm conclusions to be drawn, but the largest reasonable estimate was only equal to the earlier estimate.

On the basis of the above catch figures and the earlier estimate of pup production the mean hunting mortality in the first year from all agencies is about 36%, and since 1950 this figures applies about equally to Gulf and Front herds. Hunting of immatures and adults is however concentrated on the Front herd.

Peak catches of young by ships were 265,000 in 1951 and 300,000 in 1956. Analysis of age samples of harp seals from three sources showed that there were fewer survivors of these two year classes than after years of lower catch. Survival appears to be good following ships' catches of up to 180,000 and perhaps 200,000 young.

The catch of adults has increased from about 7,000 annually in 1930 to 1939 to some 53,000 in 1949 to 1958. The hunting mortality of adults is calculated from the statistics of catch and estimates of size of adult stock, and compared with their total mortality rate calculated from age-frequency data. It is concluded that at the present mean level of catch, hunting mortality accounts for about 1/3 of total adult mortality, which is probably not excessive but close to that which the adult stock can maintain.

The present catch of immatures, calculated in a similar way, is not excessive provided that recruitment of young remains adequate. However the catch of immatures in the moulting patches is now numerically less than before the war, in spite of a tripled catch of immatures-plus-adults, which suggests that recruitment of immatures has declined as the result of an excessive catch of young.

INTRODUCTION

Existing knowledge on the stocks of harp seals in the western North Atlantic was summarised by Fisher and Sergeant (1954) and Fisher (1955). Since 1952 no changes have taken place in the informal agreements by which Canada and Norway, the only nations at present exploiting this stock of seals by catching from ships, have attempted to regulate the catch. The only control is an informal agreement by which the starting dates for taking young are fixed. Catches since 1949 have remained at a generally high level, somewhat higher than before the war, and have taken an increased proportion of the old seals. The Fisheries Research Board has therefore continued to compile statistics of catch, to attempt population estimates from time to time, and to sample the catch in an attempt to determine whether this increased catch shows signs of depleting the stocks. The results to date are presented in this paper.

In this Circular the Gulf is the Gulf of St. Lawrence, while the Front is the area east of Newfoundland and southern Labrador. These names, used by sealing people, conveniently indicate the two breeding grounds of harp and hood seals in the western North Atlantic. The names however refer to the two icefields and not to fixed geographical areas.

THE FISHERY

Statistics

Statistics of catches of harp and hood seals by ships of all countries (at present Canada and Norway only) operating in the western North Atlantic have been compiled by the Arctic Unit from subtotals published by Norway (see Bibliography) and supplied in typescript by the area offices of the Canadian Department of Fisheries in St. John's, Newfoundland, and Halifax, Nova Scotia. Statistics are now tabulated fairly uniformly by these agencies, giving number and tonnage of ships, number of men taking part, and subtotals of catch by species (harp and hood seals) and by age-group (young, immature and adult harp seals, young and old hood seals, distinguished by pelage).

Statistics of landsmen's catches are incomplete and have had to be estimated. This stock of harp seals is hunted from Nova Scotia to West Greenland. The catch by landsmen in eastern Canada is very variable from year to year, depending on whether the ice carrying the seals is

brought close to shore. Since landsmen's catches probably account for about a quarter of the total seals killed it is felt that more complete recording of statistics by regional agencies is desirable, a topic discussed further in Appendix I.

Catches

Postwar catches of harp seals by ships are shown in Table I and graphically in Figure 1, with the proportion of young, and of immature and old seals, indicated. Following the postwar recovery of the sealing fleets, catches rose to their prewar level by 1949 and have since fluctuated round a generally high level. The mean annual catch by ships in the decade 1949 to 1958 was 262,395 harp seals, 186,369 being young and 76,063 immature and old. For comparison, the mean catch in the period 1930 to 1939 was 157,252 harp seals, 131,105 being young and 26,147 immature and old. From available data (Table I) the landsmen's catch of harp seals in eastern Canada (Maritime Provinces, Newfoundland and Labrador), probably averages about 50 thousand annually. To this must be added a catch of between 10 and 20 thousand in west Greenland and in the eastern Canadian arctic in summer, nearly all taken in Greenland.

The great majority of harp seals taken by Canadian landsmen are young, accessible from shore in March, April and May. Hook and line catches around the Magdalen Islands in April and May, as well as net catches in northern Labrador and the north shore of the Gulf of St. Lawrence in late fall sample virtually the whole populations, as is known from age samples (Figs. 3 to 6). Greenland catches in summer take many immatures, particularly first-year seals, as shown by age frequency data kindly lent by Dr. Paul Hansen of the Grønlands Fiskeriundersøgelser. The composition of the small catch in the Canadian arctic (eastern and southern Baffin Island, Hudson Bay) is currently being investigated by the Arctic Unit.

Catching effort

Catching effort has been measured by vessel tonnage. Fewer data are available for the number of men taking part, and these follow closely the index of tonnage. Following the postwar recovery of the sealing fleets, tonnage reached a maximum in 1951 and 1952 (Fig.2). There has since been a slight decrease, due to the decline in the Newfoundland fleet, which has been partly offset by an increase in numbers

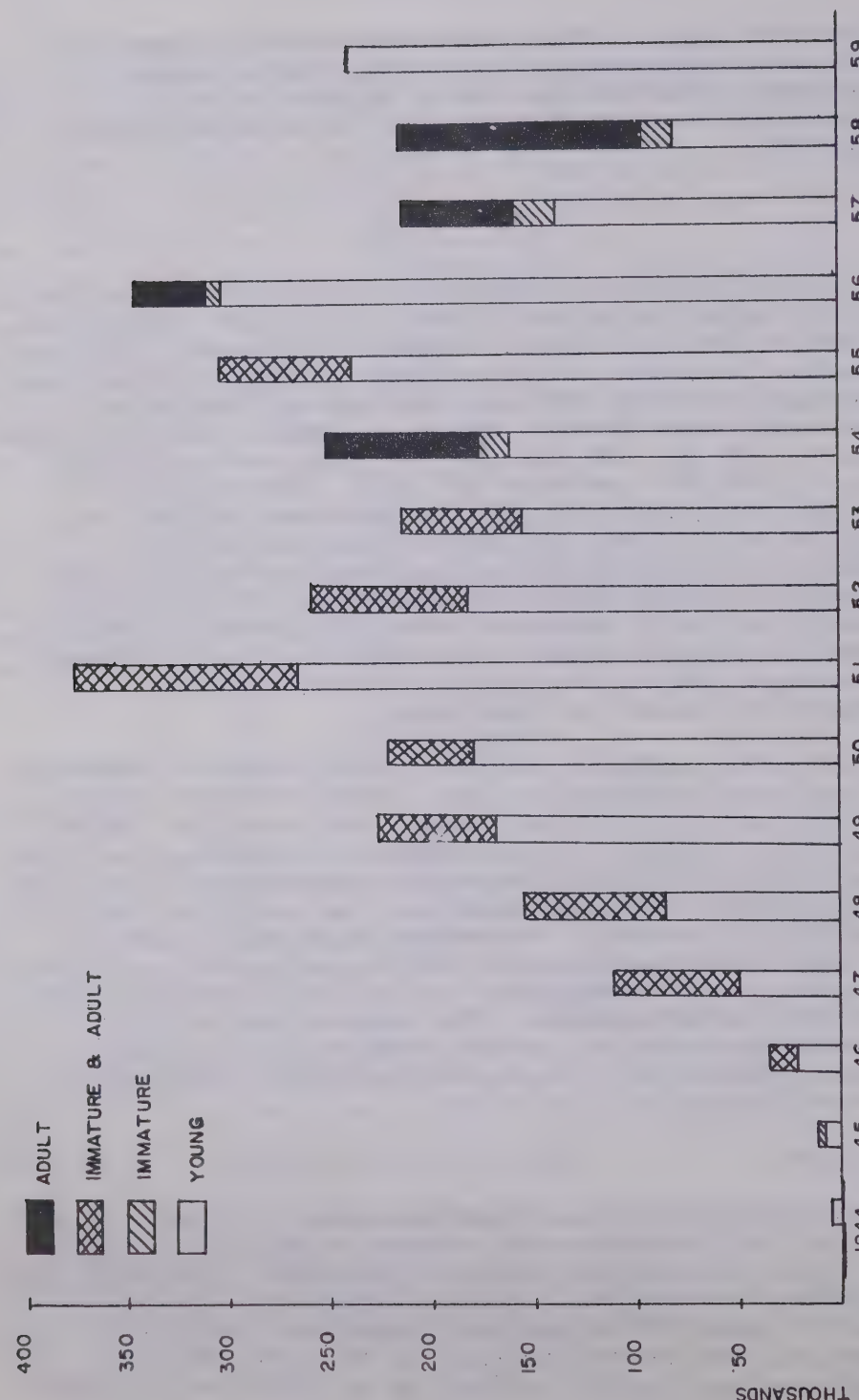

Figure 1.
Catch of harp seals by ships of all countries in the western North Atlantic in the postwar period by age group.

Table I. Catches of harp seals in the western North Atlantic.

a. Ships' catches.

Year	Young	Immature	Old	Total
1944	6,360	28	50	6,438
1945	9,516	1,637	378	11,531
1946	21,798	-15,174-		36,972
1947	49,517	-61,270-		110,787
1948	85,950	-68,874-		154,824
1949	168,315	-56,643-		224,958
1950	178,213	-43,200-		221,413
1951	265,293	-110,705-		375,998
1952	181,981	-76,376-		258,357
1953	153,743	-58,405-		212,148
1954	159,626	14,387	77,308	251,321
1955	236,424	-66,821-		303,345
1956	301,945	6,953	35,792	344,690
1957	137,721	20,927	55,510	214,158
1958	80,430	15,396	121,831	217,657
Mean 1949 to 1958	186,369	-76,063-		262,395

Table I (Continued)

b. Landsmen's catches

	Maritimes	Quebec	Newfoundland	West Greenland	Total
1949	27,000†				
1950	12,500				
1951	26,800		50,000	---	
1952	13,200		20,000	---	
1953	31,800		---		
1954	-	11,353	38,429	---	
1955	8,036	10,814	---	15,668*	
1956	2,369	41,024	5,000	10,883*	59,276
1957	228	11,483	5,000	---	
1958	3,210	6,420	53,590	---	
1959			10,400	---	

The mean of 3 years when totals were available for all Canadian provinces was 47,544

*April 1, 1955 to March 31, 1956, etc.

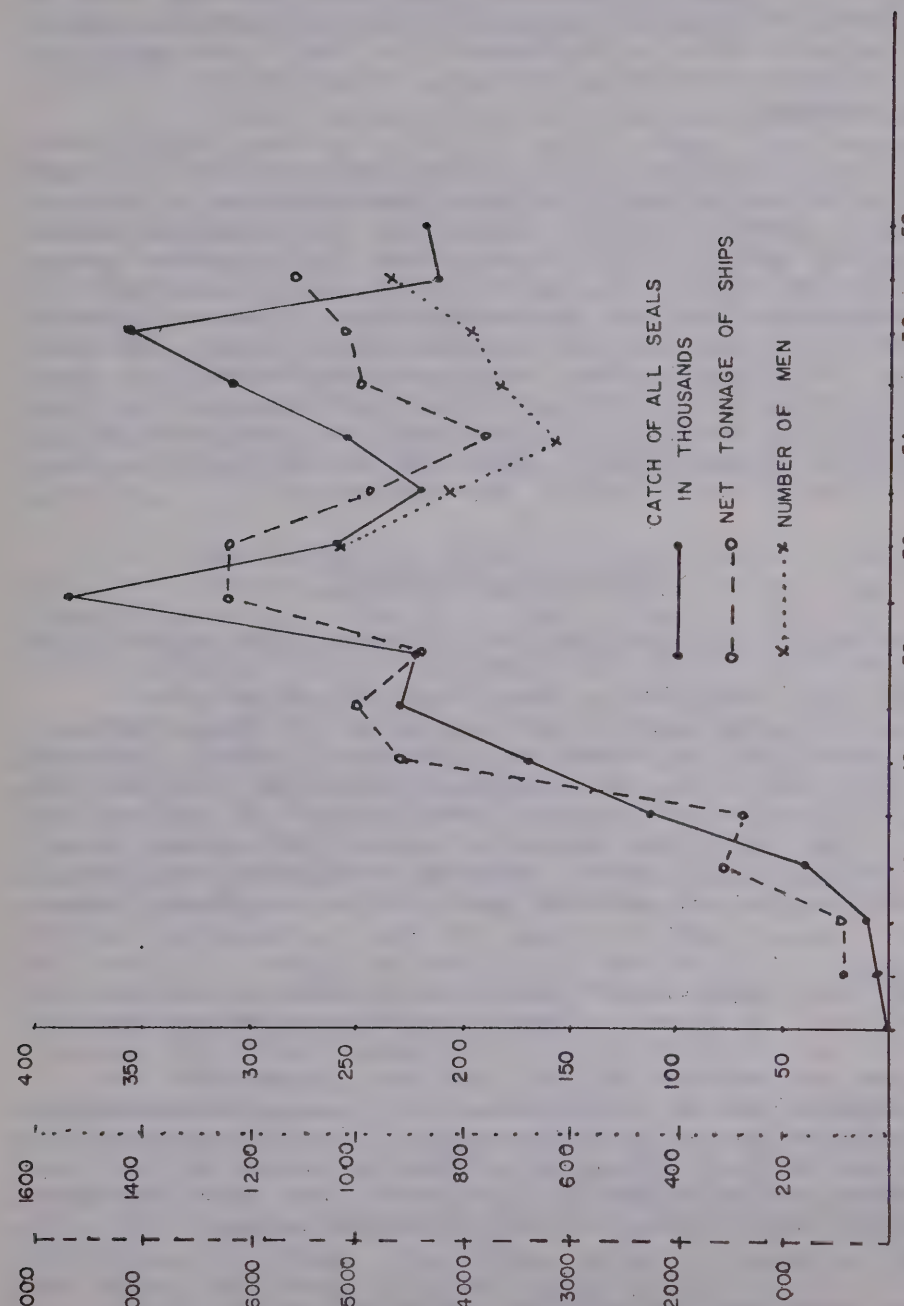

Figure 2. Catch and effort data compared.

and tonnage of Norwegian vessels. The Nova Scotian fleet has remained fairly constant in size meanwhile. At present it appears that replacements for the fleet as a whole are slightly exceeding wastage, resulting in a slowly increasing tonnage.

Figure 2 shows that the rise in catch in the post-war recovery period closely followed the increase in ship tonnage. More recently, while the fleet has remained large, there have been wide variations in catch from year to year. These must be the result of variable ice conditions and other factors affecting the accessibility of the seals to the fleet as a whole. Overall catching efficiency, measured in seals per ton, has however increased nearly twofold in the postwar period as compared with the prewar period. This is presumably the result of factors such as better ship design, greater mechanisation, improved navigational aids, and the increased use of aerial reconnaisance.

POPULATION ESTIMATES

Attempts at counting the breeding females and young were made by aerial photographic survey in 1950, 1951, 1955 (Front only) and 1959. Results of the first two surveys, and calculations of total population based upon them, were presented by Fisher and Sergeant (1954). It was concluded that the total population of breeding females was about 215,000 in the Gulf of St. Lawrence and 430,000 on the Front. The figure for the Front was however less firm than that for the Gulf, since coverage was never complete. The 1955 survey did not succeed in covering the Front completely.

In 1959 coverage of the Gulf was believed complete, and one patch of 72 square miles surveyed on March 6 was estimated to have a density of 2,020 adult seals per square mile and thus to contain 151,500 adults. On March 9 the number of adults was not obtainable but it was determined that the ratio of young to adults was 40%, which gives a minimal estimate of 60,000 pups. This was actually the catch of young seals in the Gulf by 6 ships. Later surveys would probably have given a higher total of adults and young.

On the Front one undisturbed patch was surveyed on March 10 and 11. The first survey gave an area of 31 square miles and a density of 2,000 adults per square mile, the second an area of 38 square miles and a density of 1,700 per square mile. The two estimates, 62,110 and 64,540 adults, give an idea of the accuracy of the method under

good conditions. The ice was too rough for a full count of pups but the two estimates were 36,000++ and 41,000+, agreeing with visual estimates of between 75 and 90% of pups born.

A more southerly patch was surveyed on March 10 when pupping was at a fairly early stage, with masses of unpupped adults concentrated at its western edge. With an area of 34 square miles and a mean density of 1,968 adults, the total number of adults was 67,000. On March 12 a second survey was made and the new area assessed at 50 square miles. By this time 10 ships were congregated around the edges and some killing had taken place; the density of adults was considerably lowered and many had entered the water. On the least disturbed photographic line the density of adults was 1,825 per square mile, which would give a total of 91,250 adults. Pupping was at an early stage. Estimates of pups were more than 15,000 on March 10, and about 20,000 on March 12.

The estimated total of adult seals in both patches then lay between 130,000 and 155,000, with at least 60,000 young born at the time of survey. Twelve ships took about 95,000 young from these two patches between March 10 and 21.

A further large patch was found by the industry's plane on March 21, after our survey had ended. The area was given as about 30 miles long by an average of 6 miles wide, thus giving an approximate area of 180 square miles. The density was described as high at the northern end, low (due to loose ice) at the southern end, and lower than the density of the Gulf patch seen by the same observer. An assumed density of 1,800 adults to the square mile would give an estimate of 324,000 seals in this patch. However, the area is a rough estimate and the density a guess. Thirteen ships took 85,000 young seals from this patch before it was dispersed by a storm.

To summarize, some 280,000 to 305,000 adult harp seals were estimated in the Gulf and on the Front by aerial photographic survey, and the addition of the unsurveyed patch on the Front might give a grand total of the order of 604,000 to 629,000. These are assumed to be all or nearly all adult females which would give a similar figure for production of young. The total catch of young by ships in both areas was about 240,000 young seals.

There is therefore no firm evidence that the earlier estimate of 645,000 young produced annually is substantially incorrect, although it is unlikely to be increased. As a working figure, it is therefore assumed that the population of harp seals in this stock remains at 3 million, with the Front stock 2 million, and that annual pup productions are 430,000 on the Front and 215,000 in the Gulf. These figures are used in lieu of more precise figures to calculate mortality rates. A further aerial survey is desirable to improve the estimate.

HUNTING INTENSITY OF GULF AND FRONT HERDS

Prior to about 1951 catches in the Gulf were small compared with those made at the Front. However the Nova Scotian fleet and one Norwegian ship have since this time concentrated on catching the young of the Gulf herd. Few immatures and adults are taken here by the ships because the ice departs before the moulting period, but catches of immatures and adults by a longline fishery at the Magdalen Islands in April and May show that at least some of the Gulf immatures and adults moult in the water. Catches in the Gulf and at the Front, so far as statistics are available, are shown in Table II. These show that from 1951 the annual catch of young by all agencies in the Gulf has lain between 38,000 and 95,000 with an average of 76,500. This represents 36% of the estimated production in the Gulf of 215,000 young. The average catch on the Front in the same period is more than 142,000, data on landsmen's kills often being absent. This represents 33% of an estimated production of 430,000. In other words, the intensity of hunting of young is now about the same in the two areas.

STUDIES OF AGE FREQUENCY

Sampling

Sampling the catch to study the age-frequency has proved a valuable research tool, giving information on the relative strength of each year-class, following known catches of young in the particular year. Aging is carried out by counting the growth layers in one of the lower canine teeth.

Table II. Catches of young harp seals by subarea.

Year		Gulf of St. Lawrence		Front	
1949	Ships	22,000		142,054	
	Landsmen	16,000			
			38,000		
1950	Ships	21,000		146,079	
	Landsmen				
1951	Ships	64,433		110,542	
	Landsmen	11,800		50,000	
			76,233		160,542
1952	Ships	51,718		127,621	
	Landsmen	5,000		20,000	
			56,718		147,621
1953	Ships	4,200		157,358	
	Landsmen	50,000			
			54,200		
1954	Ships	64,500		78,000	
	Landsmen	10,000		35,584	
			74,500		113,584
1955	Ships	76,131		160,193	
	Landsmen	18,036			
			94,167		
1956	Ships	55,441		244,304	
	Landsmen	38,000		5,000	
			93,441		249,304
1957	Ships	63,035		74,686	
	Landsmen	10,500		5,000	
			73,535		79,686
1958	Ships	72,000		4,357	
	Landsmen	18,000		53,590	
			90,000		57,947
1959	Ships	est. 60,000		est. 180,000	
	Landsmen			10,400	

Sampling of southward migrant seals in the early winter has been carried out yearly since 1952 from La Tabatiere on the Quebec North Shore; 1957 alone produced no sample since early formation of ice cut down the catch. The seals are taken by net in late December and early January; the year referred to here is the new one. It is not known whether these migrating seals are a sample of the whole population or of the Gulf-breeding herd only. Similar net samples were obtained from northern Labrador in October and November of 1952 and 1953; these showed much the same representation of the younger year class as samples from La Tabatiere (Fig.6) and were consequently discontinued.

Sampling in the Gulf of St. Lawrence in the spring has more recently been carried out in the Magdalen Islands. The samples are collected by the Quebec Dept. of Fisheries and the teeth read by this Unit. An adequate sample for age-frequency analysis was collected here in 1957. The seals are taken largely by hook and line, and comprise adults only in March with immatures as well in April and May.

The samples both from La Tabatiere (Figs. 3 and 4) and from the Magdalen Islands (Fig. 4) are deficient in immatures, the numbers increasing with age until (variably) the 3 to 5 year-olds are the largest class. The explanation for this deficiency of immatures in the early winter is known, since tag recoveries show that many first year seals, but a smaller proportion of those in their second year and so on, remain in Greenland waters until January and February. However in April and May one would expect a higher representation of immatures in the Gulf, since full numbers are found in the moulting patches of the Front at the same time (Fig. 5). Their absence from the Magdalen Islands is probably to be explained by segregation. Thus, the seals taken at the Magdalen Islands are feeding on schools of herring, and the younger immatures may largely feed elsewhere on smaller food such as capelin. One sample from the Gulf pointed to some such segregation; of 484 harp seals sampled as they moved out of the Gulf at Blanc Sablon in June 1957, almost all were young of the year with a small percentage of immatures and practically no adults (Fig. 4).

Age-sampling of moulting seals at the Front ice, east of Newfoundland, was carried out in April of 1952, 1953 and 1954 by investigators of the Fisheries Research Board. The samples come from seals shot by gunners of the sealing ships. With the help of the industry, a small

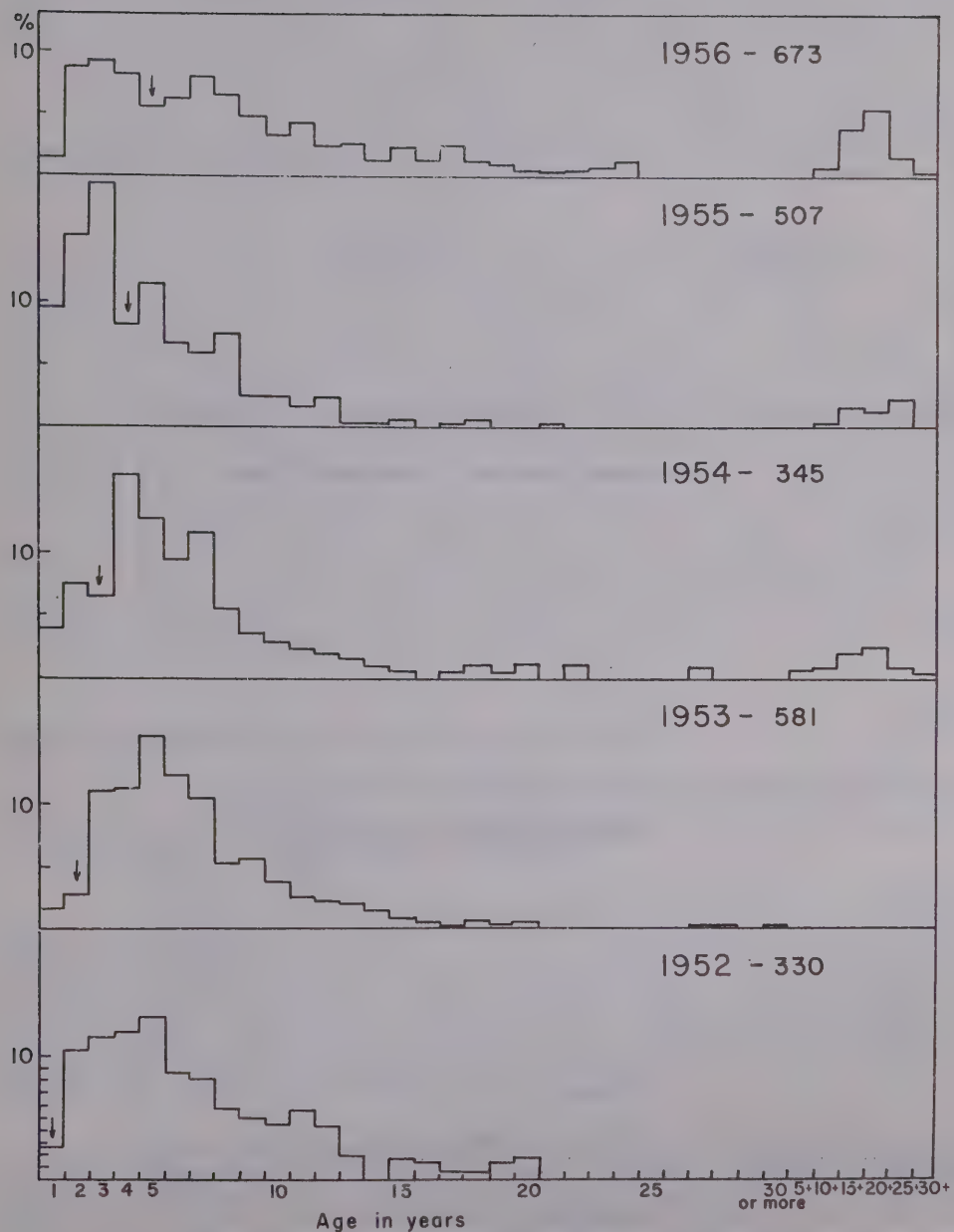

Figure 3.

Age samples of harp seals from La Tabatiere through a number of years. The year-group born in 1951 is represented by a vertical arrow.

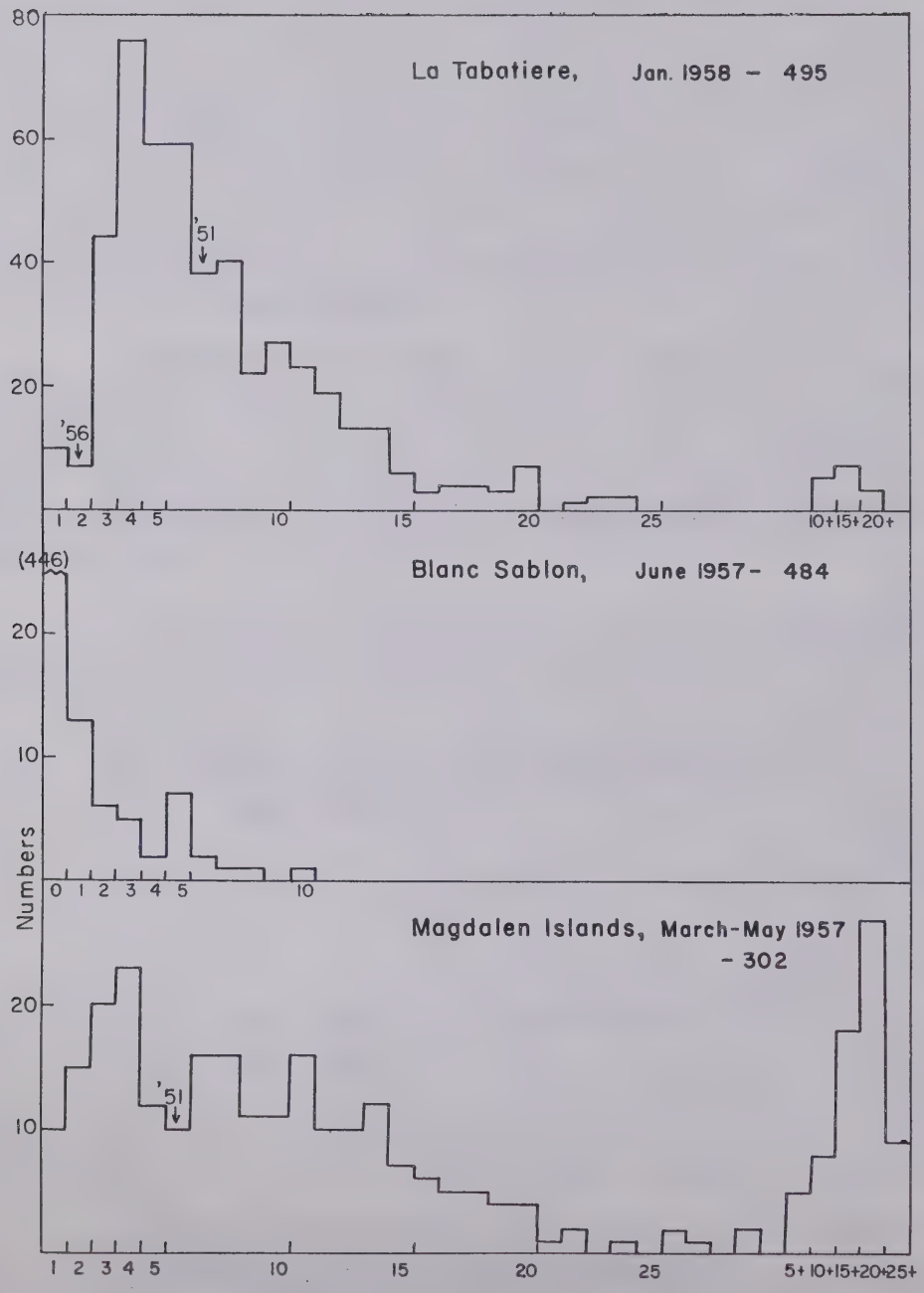

Figure 4.
Further age samples from La Tabatiere, and two other age samples from the Gulf of St. Lawrence.

sample was again obtained in 1957 and an adequate sample for age-analysis in 1958. These samples (Fig. 5) contain all age-classes fairly well mixed, and (in contrast with the Gulf samples) a very high proportion of young immatures. This proportion must be higher than in the population, since calculated mortality rates between one and two years reach as much as 60%. This is probably because the younger animals are tame and so more easily shot than adults. It is known also that the adult females are at first not fully mixed with the moulting groups, being virtually absent until about April 20, so that samples taken before this time show the age-composition essentially of the adult males, and of the immatures of both sexes.

Because the immatures are fully represented at the Front, these samples show the fate of a year-class within two years of birth--the one-year olds are too highly selected to show lowered survival but a fall in frequency can be detected among the two-year olds. In contrast, the poor representation of the younger immatures in Gulf samples means that the fate of a year-class does not show clearly until two or three years have passed, or unless the sample is very large. In the samples as a whole it appears that the relative strength of a year-class can be detected up to 5 or 6 years; after this age, errors in age determination in a proportion of teeth smooth the histogram and obscure the real fluctuations in year-class strength. Again, increasing the size of the sample allows year-class strength to be detected to a later age.

Annual changes in survival of the young

The results of age-analysis of the samples are summarised in Table III. Figures 3 to 7 show the age-frequencies of the valuable samples.

The samples from La Tabatiere (Figs. 3 and 4) show a consistent scarcity of the 1951 year-class, discernible in the samples from 1953 to 1958. By contrast, no consistent lowering can be detected in the year-classes 1947 to 1950, and the classes of 1952 to 1954 seem to have survived well. The large sample obtained in 1958 also shows the 1956 year-class to be low.

The sample from the Magdalen Islands obtained in 1957 (fig. 4) also shows poor survival of the 1951 year-class, although the fate of the 1956 year-class is not yet apparent.

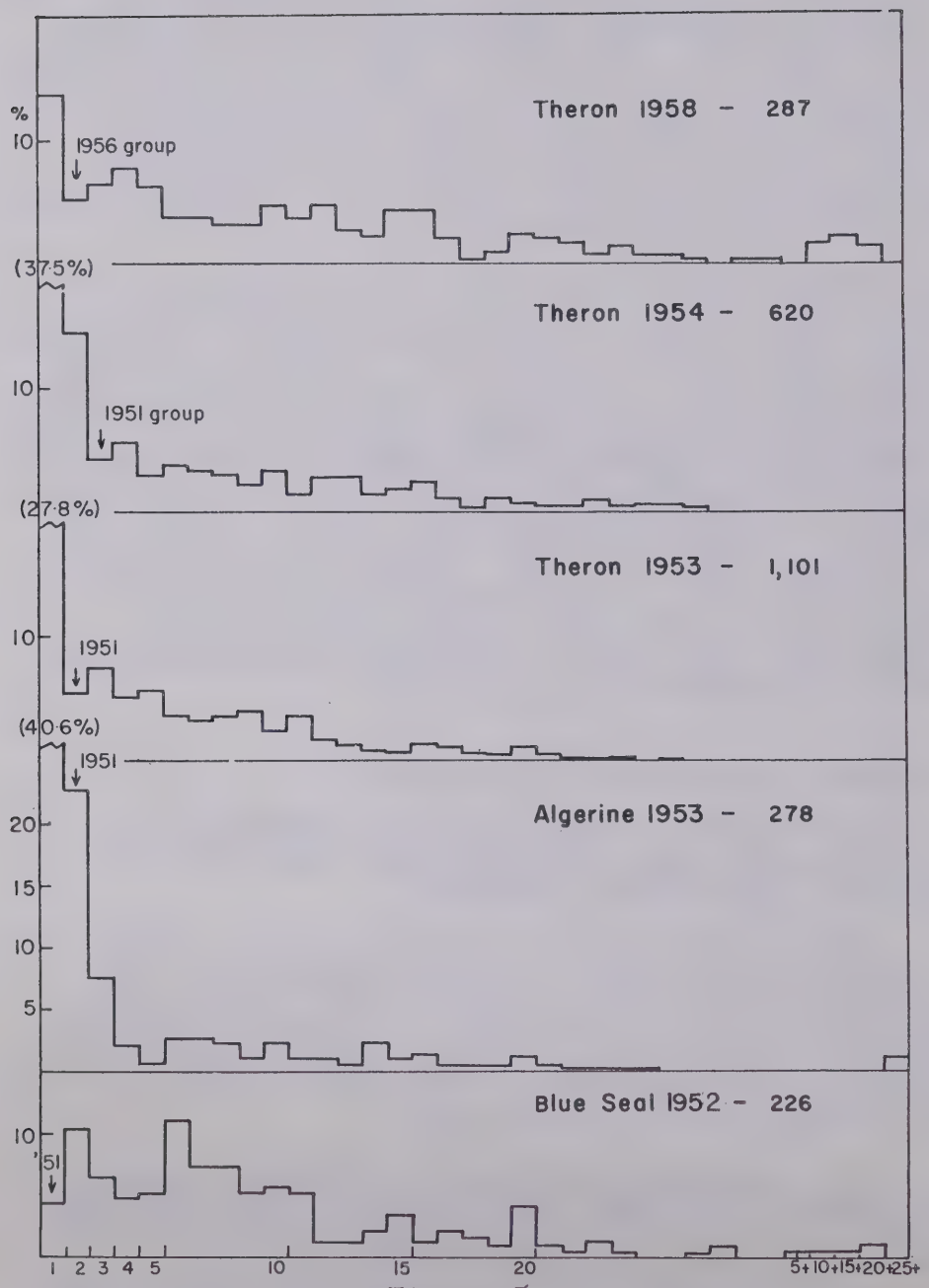

Figure 5.
Age samples from the "Front" through a number of years.

The samples from the Front (Fig. 5) show a similar sequence to those from La Tabatiere. Thus in 1952 a small sample (226) from one ship showed few 1-year-olds. This could have been due to chance sampling, since the area of hunting was in the north of the moulting area of the time, and many of the immatures first segregate to its south.

In 1953 a large sample (1,101) from one ship's catch showed a poor representation of the 2-year-old 1951 group; a second sample from another ship did not show this but the sample was considerably smaller (278). In 1954 a sample of 620 from a single ship's catch showed the 1951 group to be low. No adequate sample was available from the Front again until 1958; the sample of 278 taken in that year came from one ship's catch in the second part of April. It shows a smaller proportion of immatures than in the samples of 1953 and 1954, probably because by this time of the moult the immatures are thoroughly mixed with the adults. The 1956 year-class is clearly below expected numbers, with 1955 possibly a little low also, and 1953 and 1954 classes in good condition. The fate of the 1951 class, in such a relatively small sample, is no longer clear. A glance at Figure 1 shows that 1951 and 1956 were years of very high pup kill, 260,000 and 300,000 animals respectively. Thus the two years of high kill were followed by a fall in the survival of the same two year-classes relative to other year classes, indicating that the former suffered a very high mortality in the first year of life. We do not know what variations occur in the natural mortality of the young from year to year; there is some evidence that occasional catastrophes may occur in the first few weeks, due to destruction of floes by gales, and to rafting of packed ice by pressure. The decline of the 1951 year class alone could therefore be attributed to a hunting mortality, not in itself excessive, superimposed on a high natural mortality rate. However the identical fate of the 1951 and 1956 year classes, both following years of very high kill, makes it virtually certain that the low survival rates are the result of high rates of hunting. The year groups of 1952 to 1954 survived well; the highest catch in these years was 182,000. The 1955 year class may possibly be a little low in the La Tabatiere sample of 1958 and the Front sample of the same year, following a catch of 236,000. However the comparison between a poor and a good survival rate by this method is only relative, because we do not have years of negligible hunting which would act as controls.

Table III. Summary of results from age sampling.

Year	Month	Locality	No. in Sample	Peak Age yrs.)	Low Years
1952	Jan.	La Tabatiere	673	5 (1947)	-
	April	Front	223	2 (1950)	1951?
1953	Jan.	La Tabatiere	581	5 (1948)	1951?
	April	Front	1,100	1 (1952)	1951, 1949?
1954	Jan.	La Tabatiere	345	4 (1950)	1951
	April	Front	618	1 (1953)	1951, 1949?
1955	Jan.	La Tabatiere	506	3 (1952)	1951
1956	Jan.	La Tabatiere	673	3 (1953)	1950?,1951?,1955?
	Mar-May	Magdalens	155	2 (1954)	too small
1957	Front		70	too small	too small
	Mar-May	Magdalens	302	4 (1953)	1951
1958	Jan.	La Tabatiere	495	4 (1954)	1956
	April	Front	289	1 (1957)	1956, (1955)

(The very low kill of 80,000 young by ships in 1958 will act virtually as such a control in future samples-see Table I).

The annual production of young has been estimated at 645,000. The annual kill by ships from 1949 to 1958 averaged 186,000. The catch of first-year seals by Canadian landsmen is high, possibly averaging 90% of the total landsmen's catch, or some 42,800. The catch of first-year seals in Greenland is estimated from the total catch, and from age frequency data not shown here, to be about 3,000. The total of 232,000 young seals taken annually then represents 0.36 or 36% of production. In order to estimate total mortality in the first year it would be necessary to add natural mortality, an accurate estimate of which is not yet possible.

Mortality rates of adults and immatures

The effect on the stock of the catch of immatures and adults cannot be determined from variations in the survival rate from year to year since the catch (largely seals shot at the moulting patches) falls more or less equally over all age-groups from one-year olds and up. The adult females, it is true, suffer little mortality at the moulting patches until late April (Fisher and Sergeant 1954), but this relative freedom is partially offset by the casual killing of breeding females with their pups. In March 1953 the writer estimated that on one patch on the Front the kill of breeding females was about 5% that of pups; if this holds true at most breeding patches the mean annual kill of breeding females would be about 9,000. Fortunately the deliberate killing of females with their pups is rarely practised by sealing ships.

It is possible to calculate the total adult mortality, i.e. that due to natural deaths and hunting combined, from year to year by analysis of the age-frequency histograms. The kill of adults is known from the statistics, and it can then be seen what part of the total mortality this hunting mortality represents. We have for this purpose treated samples from La Tabatiere and the Front separately since these show very different slopes, i.e. mortality rates, for the adult populations. The method of analysis was to sum the age-samples over a number of years in order to get rid of variations in survival rates from year to year, to smooth the total figures, and by plotting a catch-curve to calculate year to year mortality rates. Adults only can be treated, for the following reasons:

(a) in the La Tabatiere samples the immatures are not fully represented; (b) in the Front samples the immatures are believed over-represented, as well as being partially segregated from the adults, so that immature and adult groups must be treated separately. Moreover, in older adults, the proportion of teeth which cannot accurately be aged rises steadily. These teeth cannot be assigned a place in the histogram and must be placed separately, as 10 plus, 15 plus, etc. Their absence means that apparent mortality rates of older adults are higher than true mortality rates. For these reasons, we have measured mortality rates for animals aged only between 6 and 11 years. Calculations are presented in Tables IV and V.

Total mortality rates for Gulf (La Tabatiere) adults work out at about 0.19, for the Front adults, 0.079. The much higher value for mortality of the Tabatiere seals seemed suspect, since there is no evidence that the adults in the Gulf suffer higher hunting mortality, and indeed if they moult in the water and are free of hunting they should suffer a lower total mortality than the heavily hunted adults at the Front. The only alternative explanation for the high apparent mortality of Tabatiere adults is that these samples are not taken at random from the population, older animals being progressively less well represented.

Fortunately another age-series of shore-caught seals was available, which strongly supported the second explanation. Figure 6 shows the age-frequency of 751 harp seals caught by net at three sites in northern Labrador in October-November 1952. Samples from the three sites were equal in number and were summed directly. Figure 6 also shows for comparison the sample taken at La Tabatiere a few weeks later, in January 1953. The much higher representation of adults in the sample from northern Labrador is striking. (The three sub-samples, respectively from Hebron, Nutak and Nain going from north to south, showed an interesting trend: Hebron showed a peak at 4 years of age, Nutak at 5 to 9 years, and Nain at 8 years. In other words, the most northern station showed considerably fewer adults than the two more southerly. The reason for this is not entirely clear, although it suggests that the older adults tend to lead the migration. In 1958 three sub-samples taken early, halfway and late in the catching season from La Tabatiere also showed that the adults tended to pass through first, the first sub-sample having a peak at 4 to 6 years, the second at 4 years, and the third at 3 to 4 years. These examples illustrate how subtle may be the variations in age-frequency of samples from different

Table IV. Front moulting groups 1952 to 1954: age frequencies and estimated total mortality. Those of immatures are believed to be unrealistically high.

Age	1952	1953 Algerine	1953 Theron	1954	Total	Smoothed Total	Total Mortality rates
1	10	113	306	232.5	662	662	
							(.515)
2	24	63	61	90.5	239	321	
							(.504)
3	15	21	83	25.5	145	159	
							(.283)
4	11	6	55	36	108	114	
							(.228)
5	12	2	60	18.5	93	98	
							.061
6	25	8	40	24	97	92	
							.065
7	17	8	35	21	81	86	
							.052
8	17	7	41	19.5	85	81	
							.079
							.086
9	12	3	44	13	72	74	
							.081
10	13	7	26	20.5	67	68	
							.129
11	12	3	43	8	66	61	
12	3	3	21	18	45	49	
13	3	3	18	18	41	39	
14	5	6	10	9	30	33	
15	8	3	9	12	32	33	
16	3	4	15	16	38	34	
17	5	2	14	7	28	28	
18	4	2	9	2	17	21	
19	2	2	8	8	20	22	
20	9	4	12	4	29	23	

Table IV (continued)

Age	1952	1953 Algerine	1953 Theron	1954	Total	Smoothed Total	Total Mortality rates
21	2	2	7	2	13	15	
22	1	1	2	2	6	9	
23	3	1	1	5	10	8	
24	1	1	2	1	5	8	
25 or +	3	1	1	5	10	8	
5 +	1				1	1	
10 +	1		19		20	20	
15 +	1		62		63	63	
20 +	3		95		98	98	
25 +		3	1		4	4	
30 +			1		1	1	
Total	226	278	1,101	620	2,225	2,333	

Table V. Fall migrants: age frequencies and total mortality rates of adults.

a. northern Labrador 1952				b. La Tabatiere, 1952 to 1956			
Age	Number	Smoothed Number	Total Mortality rates	Age	Percent	Smoothed Percent	Total Mortality rates
1	3	3		1	3.9	3.9	
2	20	22		2	9.1	9.4	
3	44	42		3	11.5	10.8	
4	59	59		4	11.1	11.3	
5	74	70		5	11.6	10.7	(.053)
6	72	69	Mean	6	8.4	9.2	.14
7	57	61	0.096	7	8,4	7.9	.14
8	57	54		8	6.5	6.5	Mean .18
9	46	49		9	4.7	4.9	0.19 .25
10	45	45		10	3.7	3.8	.22
11	44	43		11	3.0	3.1	.18
12	38	39		12	3.0	2.7	
13	36	33		13	1.6	1.8	
14	22	25		14	1.1	1.2	
15	18	21		15	0.9	0.9	
16	26	22		16	0.8	0.8	
17	17	19		17	0.5	0.7	
18	15	15		18	1.0	0.8	
19	12	11		19	0.6	0.7	
20	5	9		20	0.6	0.7	

Table V. (continued)

a. northern Labrador 1952

Age	Number	Smoothed Number	Total Mortality rates
21	12	9	
22	6	7	
23	5	4	
24	-	3	
25	6	5	
26	6	5	
27	2	3	
28	1	1	
29	-	1	
30	1	1	
30 +	2	1	
Total	751	751	

b. La Tabatiere, 1952 to 1956

Age	Percent	Smoothed Percent	Total Mortality rates
21	0.8	0.6	
22	0.2	0.3	
23	0.1	0.1	
24	0.1	0.3	
25 or over	0.3	0.4	
5+	0.2	0.2	
10+	1.1	1.1	
15+	2.0	2.0	
20+	2.6	2.6	
25+	0.5	0.5	
30+	0.1	0.1	
	100.0	100.0	

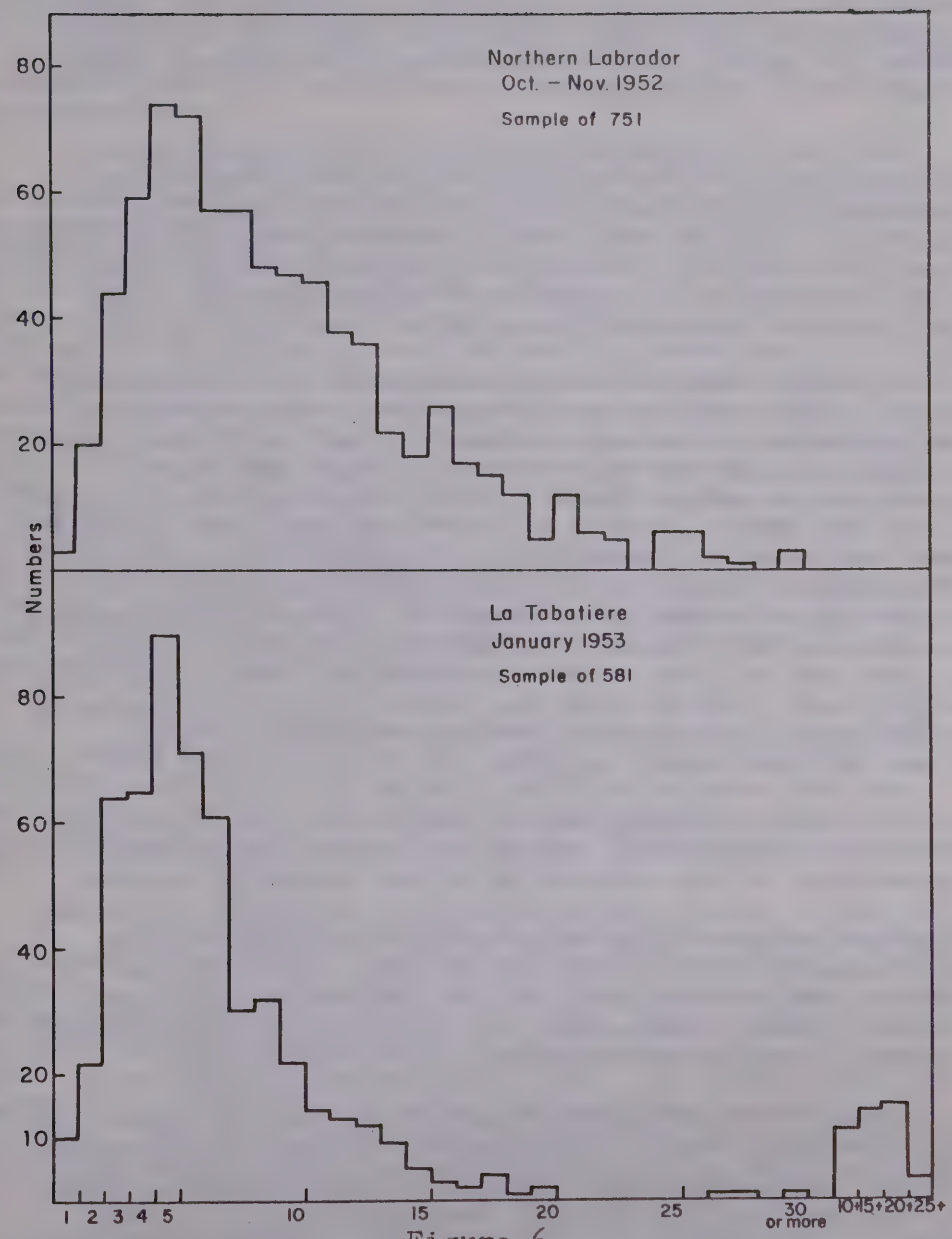

Figure 6.
Two age samples of shore-caught harp seals in the same year. The sample from northern Labrador (above) shows a greater representation of adult seals than that from the Quebec North Shore (below).

sites on land. No such variation should be expected from an adequate series of adults shot at the moulting patches, and more trust can therefore be placed in mortality rates calculated from this source. However, as mentioned above, it is largely the adult males which are shot at the moulting patches in April, and thus male mortality rates which are measured from these samples.

The mean annual mortality rate of adults aged 6 to 12 years from northern Labrador is 0.096. This is in better agreement with the value of 0.078 obtained from Front adults. Allowing for somewhat greater mortality rates in old age, which will increase slightly the overall mortality rate of adults, we suggest a figure for the total mortality rate of adults of about 0.09 or 9% per annum.

Now the annual take of adults is known from the statistics. In recent years (1954, 1956, 1958) we have a complete breakdown of catches of adults and immatures; in other years the catch of the two groups has not been separated for all ships (Table I). In 1954 the adult catch was 77,000, in 1956 - 36,000, in 1957 - 55,500, and in 1958 - 121,800. The catch of immatures-plus-adults between 1949 and 1958 averaged 76,083 with upper and lower limits of 137,000 and 43,000. The percentage of adults in subsamples of the catch varied, for reasons we shall discuss below, ranging from 40% in 1950 to 89% in 1955 and 1958. The mean for the 10 years 1949 to 1958 was probably about 70% adults. The mean kill of adults was therefore 76,083 x 0.7, or 53,000; and of immatures, 23,000.

The total population of adults was estimated by Fisher and Sergeant (1954), using the aerial survey data plus a knowledge of the fertility of the breeding females (80%). The adult females were assumed to be equal in number to the pups, namely 645,000 plus a 20% addition for the infertile females, giving 774,000 in all. If the sex ratio of the adults is unity, as is that of the newborn young (Fisher 1955), there will be an equal number of adult males, giving a total adult population of 1,548,000.

Thus the mean hunting mortality rate of adults is $\frac{53,000}{1,548,000}$ or 0.034. This represents a little more than one-third of our estimated total mortality rate of 0.09. The highest recorded kill of adults, that of 121,800 in 1958, represents a mean mortality rate of 0.79, almost equal to our estimated total mortality rate. If we assume that about

one-half the total mortality rate is the maximum safe level for adult hunting, a catch of 1,548,000 x 0.05, or 77,400, could be maintained. Any calculation of the precise sustainable level would demand knowledge of the level of recruitment of immatures to the breeding stock and indeed construction of a complete life table. We lack knowledge of the true mortality rates of immatures and so cannot as yet carry out this operation.

Total mortality rates of immatures cannot yet be calculated because samples of immatures are not random, for the reasons explained above. Thus, for example, calculated mortality rates for Front immatures are over 50% for each of the first two years ~~of life~~ (Table IV), figures which we believe are too high to be real. Fisher and Sergeant (1954) calculated the average total mortality rates over the first six years of life, a figure that does not have great value since these rates must decrease exponentially from a high figure in the first year of life to the comparatively low level of the adults on attainment of maturity. Briefly, the method is to calculate the six-year old group as a percentage of the total adults, six years old and up, using the age samples. Then, since the total number of adults is known, the total number of six-year olds can be calculated. These being the survivors after six years of mortality of a known crop of young, the average mortality over this six-year period can be calculated.

The average values calculated were 0.25 for the Front, using moulting samples, and 0.14 for the Gulf, using Tabatiere samples. Having more extensive data from the same sources we have re-calculated these rates and obtain slightly lower figures, 0.21 for the Front and 0.13 for the Gulf.

Doubt may be thrown on the calculations based on the Tabatiere samples, because of their low representation of adults. However another calculation is possible using the northern Labrador samples of 1952, which will give mortality rates of immatures of the whole herd, Gulf and Front. The rate was found to be 0.18. It should then be possible to calculate the rate for Gulf immatures by subtraction. If 1/3 of the animals breed at the Gulf and 2/3 at the Front, then the average mortality rate for the Gulf immatures will be given by the formula:

$1(a_x) = 3(a_t) - 2(a_y)$ where a_t = mortality rate of immatures of whole herd (0.18)

a_x = ditto for Gulf immatures

a_y = ditto for Front immatures (0.21)

Substituting, the value of a_x obtained is 0.12. This is close enough to our previous estimate of 0.13 to give confidence. A lower mortality rate of Gulf immatures seems reasonable, not only because the young suffered a lower hunting intensity than on the Front up to 1950, but also because the immatures (if they moult in the water) are subject to less hunting mortality.

The contribution of the hunting of immatures to their total mortality rate can be roughly estimated. The kill of immatures on the Front between 1949 and 1958 has been estimated at 23,000. Age samples from the Front allow one to divide this catch among the immature year-groups. At the same time the total numbers of immatures can be estimated using a constant mortality factor; as explained above this is an overestimate as mortality rates start high and decrease. The hunting mortalities in each year on this basis are as follows:

Age	Estimated Population	Estimated Catch	Hunting mortality
1	330,000	11,260	0.034
2	260,000	5,450	0.021
3	208,000	2,700	0.013
4	162,000	1,930	0.012
5	128,000	1,660	0.013
Total	1,088,000	23,000	Mean 0.021

In fact we know from the mean total catch of young that the hunting mortality rate in the first year of life (age 0) is 0.36; and we might guess that the total mortality rate in the first year, including natural mortality, is not less than 0.5 and possibly more. From a production of 430,000 young a mortality of 0.5 would

leave only 215,000 immatures instead of 330,000. A kill of 11,260 at age 1 is then equal to a mortality rate of 0.05. This is still a low rate. We conclude that the hunting mortality rate of immatures is not at present excessive, even at age 1, provided that recruitment is maintained.

DECLINE IN THE CATCH OF IMMATURES

It is necessary to add this proviso because, although the kill of immatures and adults has tripled since the war, from a mean of 26,000 in 1930 to 1939 to one of 76,000 in 1949 to 1958, the catch of immatures in years for which separate data are available has actually declined. Thus, in 1930 to 1939 the mean catch was 19,459 out of 26,147 or about 75% of the total immature-old seal catch; whereas in 4 recent years it averaged 14,416 out of 72,610 or about 20%.

Part of this decline is the result of changed hunting practice. Figure 8 shows the percentage of immatures in catches of immatures and old seals taken separately by ships from Newfoundland, Nova Scotia and Norway. It can be seen that the highest percentage of immatures is (or was) taken by Newfoundland ships, and the lowest by Norwegian ships. The explanation of this seems to be that the Newfoundland ships hunted early in the moulting season, when immatures bulk high in the catches. Norwegian ships, by contrast, hunt well into May in some years and sample the patches composed of immatures, adult males and females, in which the proportion of immatures will naturally be lowered. Nova Scotian ships, hunting to the end of April, come in between.

Nevertheless changed hunting practice will not account for the absolutely smaller catch of immatures in recent years as compared with before the war, in view of the greatly increased catch of adult seals. There is a suggestion in Figure 7 that the percentage of immatures in catches by Newfoundland ships alone was falling progressively, from the prewar proportion of 75% to an average level of about 50%, before Newfoundland catches of immatures and old seals became too small to afford an accurate ratio. Moreover, in the earlier postwar period Newfoundland ships made late trips and yet returned with a high proportion of immatures; thus in 1951, out of 43,715 immatures and adults taken by Newfoundland ships up to early June, 60.4% were immature.

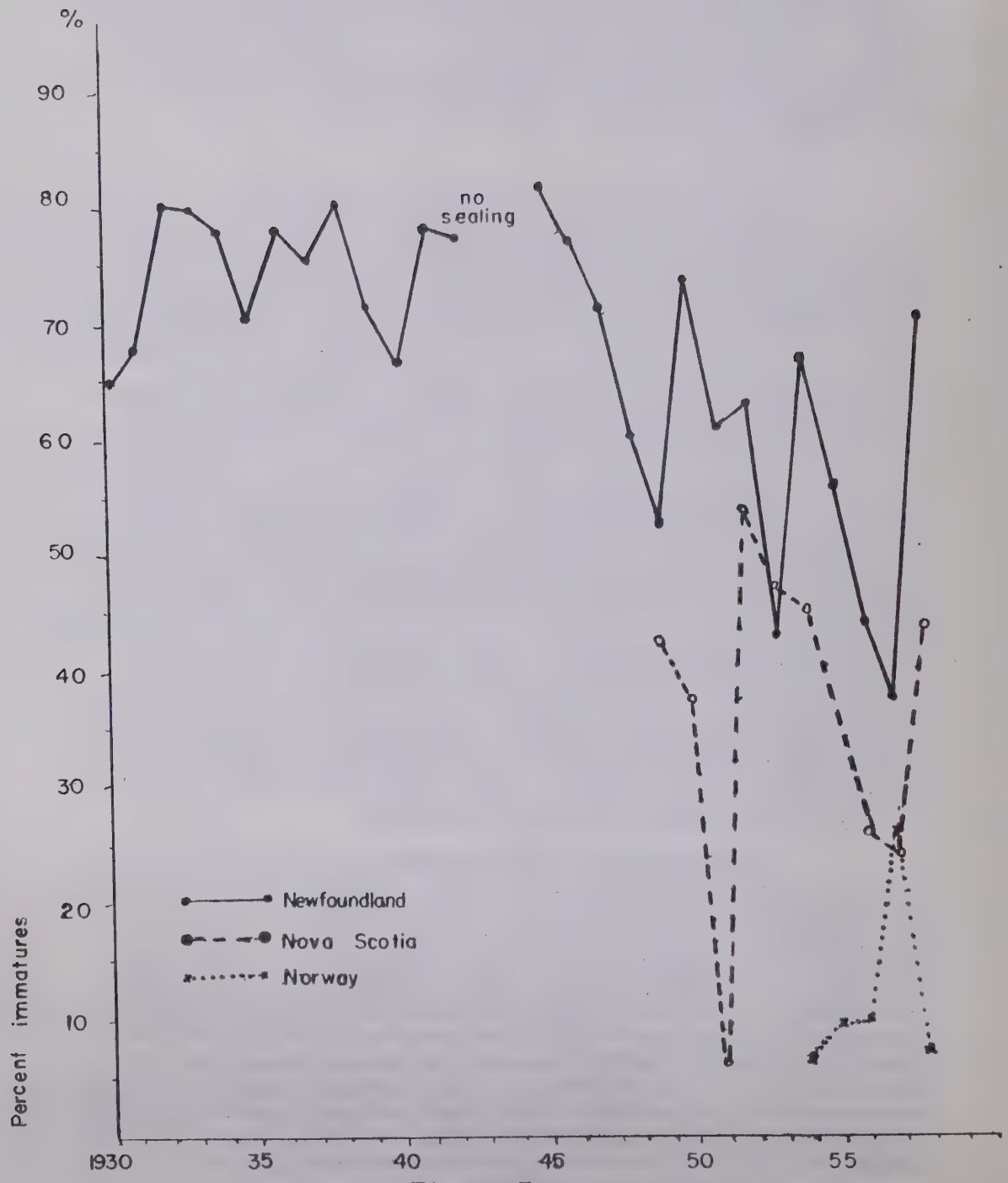

Figure 7.
Percentage of immatures in catches of immature plus old seals by ships of different origins.

If there has in fact been a fall in the availability of immatures, it can only be due to an excessive overall catch of young leading to a fall in recruitment of immatures, for we have seen that hunting rates of the immatures themselves are relatively low.

DISCUSSION

The history and present status of the three main stocks of harp seals has been reviewed very thoroughly in recent years. Surkov (1957) from aerial survey data concluded that the White Sea stock in 1953 consisted of no more than 1.2 to 1.5 million head, as compared with 3 to 3.5 million in 1928, also estimated from aerial surveys. Dorofeev (1956) published statistics of the combined catch by Norwegian and Russian ships during the period of heavy sealing between the two world wars which led to this severe reduction of the White Sea stock. In 1923 to 1927 the mean annual catch was 335,000; in 1928 to 1932, 265,000; and in 1933 to 1937, 219,500, the overall level for the whole period being 273,000. Surkov (1957) recommends a permissible catch of 8% which at present estimates of stock would comprise between 80,000 and 100,000 animals; on this basis the permissible catch of the stock in 1928 should have been between 240,000 and 280,000.

A. A. McLaren in a study of the life-table of the ringed seal Phoca hispida also suggests a safe sustainable catch of about 8% (McLaren 1958). The species has much the same reproductive rate, age at maturity and longevity as the harp seal, and the catch is divided up between young, immatures and adults in much the same way.

If we accept this percentage for the catch of harp seals, and a population estimate of 3 million animals for the western Atlantic stock, then the sustainable catch is about 240,000. The average catch of young alone by ships and landsmen together has been at about this level from 1949 to 1958, and in addition there has been a catch of adults and immatures averaging about 76,000. We have calculated that this adult-immature catch is about at its maximal sustainable level.

Thus, either the catch of immatures and adults should be greatly reduced in order to increase the breeding stock, or the catch of young should be considerably reduced in order to maintain recruitment. We have estimated the maximum sustainable catch of young by the ships at present

levels of kill of adults and immatures to be approximately 200,000. A better estimate requires knowledge of the mortality rates of immatures, as well as a more precise estimate of total population. Knowledge of the mortality rates in the first year might be obtained by a large-scale marking experiment, if this could be carried out before the opening of the sealing season. Knowledge of immature mortality rates may in the future be derived from age-samples from west Greenland, although it is possible that some selection of younger seals occurs here, as at the Front. When this knowledge is obtained, it will be possible to construct a complete life table for this population of harp seals and to calculate the effect on the life table of kills of different magnitudes.

ACKNOWLEDGEMENTS

For the preparation of statistics of seal catches the staff of the Arctic Unit is indebted not only to the various representatives of the sealing firms, but also to the persons, mostly anonymous, in the Fisheries Departments of Canada and Norway who assembled the regional figures and sent copies to this Unit. In obtaining early catch figures by sub-area we are greatly indebted to Dr. W. R. Martin of the Fisheries Research Board's Biological Station at St. Andrews, and Messrs. G. J. W. Sullivan and R. J. Thurber of the Groundfish Statistical Subunit of that Station stationed at Halifax. Dr. Birger Rasmussen of the Norwegian Fisheries Department's Marine Fishery Institute in Bergen has sent us much statistical and biological information by letter, and we have long profited from his knowledge of the Norwegian sealing industry and the biology of the seals. Dr. Paul Hansen of the Grønlands Fiskeriundersø-gelser kindly sent us copies of recent hunting statistics from Greenland.

Much help has been received from the Canadian sealing industry also towards gathering the field data presented in this paper. Karlsen Shipping Company and Bowring Brothers Ltd. arranged passage in their ships for Fisheries Research Board personnel collecting jaws and other data in the period 1952 to 1954. Messrs. Karl Karlsen and Kjell Henriksen of Karlsen Shipping Co. Ltd., and Mr. James Grieve of Bowring Brothers Ltd., have given much advice and information to assist our aerial surveys. Capt. Harold Marø arranged collection of seal jaws from

M/V THERON in 1957 and 1958. Mr. W. Rockwood of the Newfoundland Department of Public Welfare arranged similar collections from northern Labrador in 1952 and 1953, while Mr. Paul Montreuil of the Quebec Department of Fisheries has sent us collections from the Magdalen Islands yearly since 1955.

Finally the writer is indebted to Dr. H. Dean Fisher for advice and criticism in the preparation of this paper, and to the office staff of the Arctic Unit for the arduous tasks of typing and assembling it.

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APPENDIX I

RECOMMENDATIONS FOR BETTER TABULATION OF STATISTICS OF KILL OF HARP SEALS.

Ships' catches are generally satisfactory at the present time. ~~However a table showing numbers of ships and men participating in the "Newfoundland" (i.e. Western Atlantic) hunt, which appeared yearly in the Norwegian statistics, was absent for the year 1957. It would be very desirable if this could be reinstated, since otherwise information on catching effort by Norway is not generally available.~~

Catches by landsmen in Nova Scotia are sold mainly to processors in Nova Scotia and included in the returns for that province. A proportion of the Quebec catch is sold to the same processors and is also included. Details of species and age-type are given, as for ship-caught seals. Total catches of seals in Quebec (apparently all taken by landsmen) are given monthly in the statistical reports of the Quebec Department of Fisheries, but without details of species or age-type. It can however be assumed that a large percentage (about 90% or more) refer to harp seals, since the catch of other species in the Gulf of St. Lawrence is only a few hundred annually; moreover most seals are recorded taken in the months of March to May when a large number of harps is taken, especially around the Magdalen Islands and in some years on the North Shore. If statistics are taken from processors of seal pelts, as in other provinces, it should not be difficult to obtain a break-down of catch by species and age-type in Quebec. At present it appears that catches are obtained from fishermen by districts.

Landsmen's catches in Newfoundland and southern Labrador have not been included in the returns from that province in all past years, but a total figure is now given annually. This is evidently obtained from processors of pelts, so that it would be possible to obtain a break-down or cull by species and age-type for land- as well as ship-caught seals, as in Nova Scotia.

The catch of harp seals taken at Eskimo settlements in northern Labrador in 1952 and 1953 totalled less than 1,000, judging from tooth samples obtained in those years. Pelts traded were purchased by the Newfoundland Department of Public Welfare, Division of Northern Labrador Affairs. Some pelts were then sold to processors

and were presumably included in Newfoundland statistics of land-caught seals.

The catch of harp seals taken in the eastern Canadian arctic may total a few hundred to one or two thousand, mostly taken around Hudson Strait and eastern Baffin Island. Statistics of pelts traded should be available from the Hudson Bay Company but have not yet been sought. It will also be necessary to find out the percentage of pelts traded in various Eskimo communities. This percentage may be very small.

Statistics of catch of seals and other mammals in Greenland are published by the Danish Ministry for Greenland. They include details of catch by species and region. This allows separation of catches of harp seals belonging to the western Atlantic stock and taken in west Greenland, from those belonging to the West Ice breeding stock and taken in east Greenland. The point of separation of the two stocks probably lies at Cape Farewell.

It is not possible to separate catches of young seals taken by ships in the Gulf and on the Front in the statistics collected by the Fisheries Departments of Canada and Norway. This would be a very difficult task, in view of the fact that one ship may spend part of her voyage in the Gulf and proceed later to the Front. The Arctic Unit has recently begun to collect details of catch by sub-area from Canadian ships, through the intermediacy of personnel of the Groundfish Statistical Subunit of the Biological Station, St. Andrews, New Brunswick stationed at Halifax. With the help of sealing firms, good data are being obtained from officers of the sealing ships at the completion of their voyages, on catching areas, approximate dates of catching, ice conditions, and estimates of the main types of seal taken. Similar data are being obtained from Newfoundland ships, and from ships discharging their catch in Newfoundland, through the principal processing firm in St. John's (Bowring Brothers Ltd.). Similar information cannot however be obtained for non-Canadian vessels except in informal ways.

APPENDIX II

RECOMMENDATIONS FOR AERIAL SURVEYS

An aerial survey carried out once in five years is too infrequent for adequate sampling. Nevertheless the cost of a survey is large in proportion to the value of the industry, and it may have to be accepted that a survey can only be carried out rarely. The most efficient method of surveying must then be found.

It is considered that the method of population estimate based on a census of the breeding patches is unsatisfactory for the following reasons:

1. The composition of the adults is unknown (whether all breeding females or not) and cannot be determined from shipboard, because the adults go into the water. If males are present, they will be the first to go.

2. The number of pups, upon which the method is ideally based, can only be determined when births are virtually complete. By this time it is frequently found that either the ships have entered the patches, or the patches have been wheeled and dispersed by wind and current.

3. The total number of pups cannot in any case be determined unless the ice is quite smooth, as in the Gulf. As is well known, many pups hide under hummocks of ice and are invisible from the air, especially in shadows.

An alternative method of survey is to census the moulting adults when they haul out on the ice in April and May. This method has been used successfully by Russia in the White Sea (Surkov 1957). In our area it can be used on the Front, though not in the Gulf where there is no ice in mid-April and the seals either moult in the water or possibly in part join the Front herds. The method has the advantage that the composition of the moulting seals can be checked at the time of flights by observers on the ships sampling the catch. It has the disadvantage that the source of seals moulting on the Front in April and May is unknown. Some may come from the Gulf to join seals which have spent the early spring on the Front, and this influx may possibly increase through the season as the moulting seals move north of Belle Isle. Consequently

it will not be known whether the total population of immature and adult seals is being estimated, or only that part which bred or was born on the Front.

Opinions of operators will be welcomed on the merits and demerits of the two methods of survey.

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